Climate Sensitivity from Paleoclimate Simulations

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Outline

* Motivation
* CCSM4 Paleoclimate CMIP5/PMIP3 Simulations
* CCSM4 LGM vs. Proxy Reconstructions
* Climate Sensitivity
* Polar Amplification
* Conclusions

Motivation

* Evaluate CCSM4 response to Ice-age boundary conditions and forcings as compared to the latest glacial climate reconstructions.
* Establish a constraint on Climate Sensitivity using CCSM4 paleoclimate CMIP5/PMIP3 simulations

Motivation

Why use the LGM (21ka) ?

~Long stable climate

~Large Proxy Reconstructions

~Large TOA Radiative Perturbation

LGM Radiative Forcings:

ghg	~ -2.8 W m^{-2} (IPCC AR4)
Ice Sheets/Sea Level	~ -3.2 W m^{-2} (IPCC AR4)
Aerosols*	~ -1 W m^{-2} (not included here)
Vegetation*	~ -1 W m^{-2} (not explicitly included)

Total ghg+Ice Sheet Forcing [-5.5 to -7 W m^{-2}] as found in Literature…

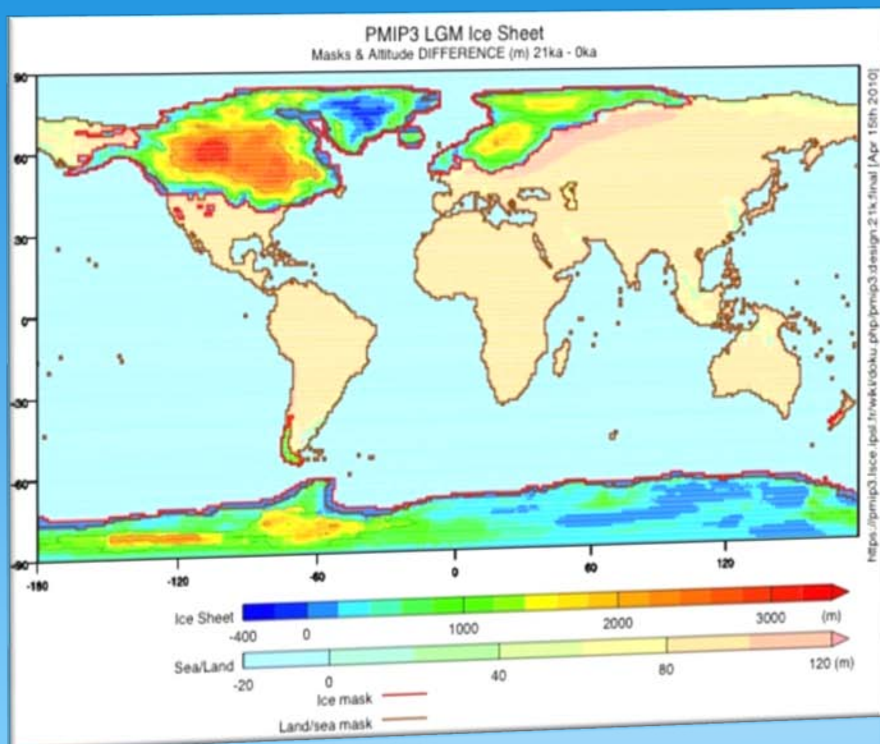
CCSM4 Paleoclimate Simulations

CCSM4: CAM4 FV1.25x.9_gx1v6

Case-name	GHG forcing	Ice Sheets	Orbital Year/SCON	Veg/Aerosols	Length
PI (1850 Control)	CO_2=284.7ppm CH_4=791.6ppb N_2O=275.68ppb	Modern Greenland and Antarctica	1990CE SCON= 1360.89W/m^2	Pre-industrial	1300
LGM	CO_2=185ppm CH_4=350ppb N_2O=200ppb	PMIP3 LGM	21,000yrs before 1950CE SCON=PI	PI	1000
LGMCO2	CO_2=185ppm	PI	PI	PI	1100
4xCO2	CO_2=1138.8ppm	PI	PI	PI	255*

Last Glacial Maximum (LGM) 21ka

Paleoclimate Modelling Intercomparison Project PMIP3



Ice Sheet Elevation change from Present day
- a new 'blended' ice sheet product

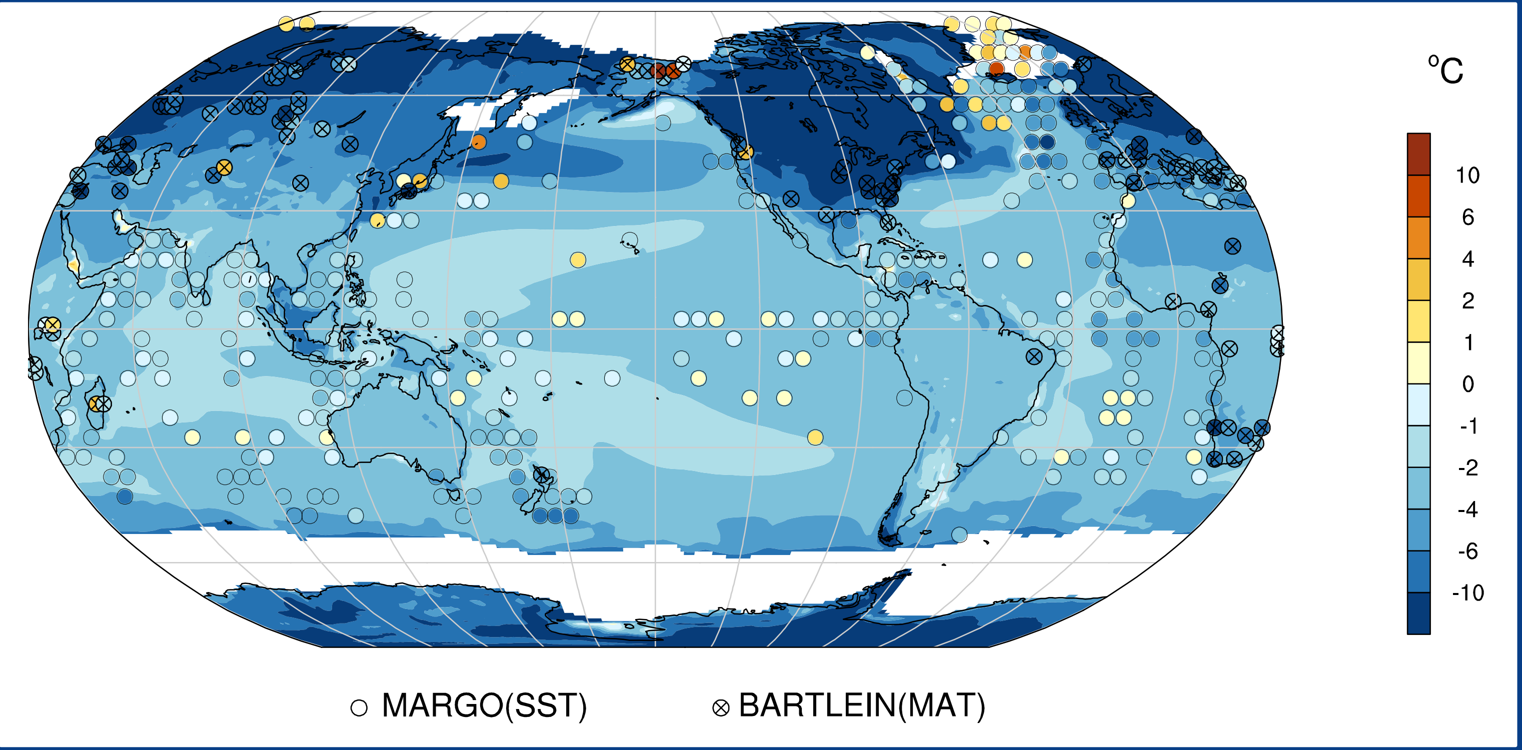
(ICE-6G v2.0, Argus and Peltier 2010; MOCA, Tarasov and Peltier 2004; ANU, Lambeck et al. 2010)

LGM vs. Glacial Proxy Reconstructions

[Annual Mean LGM-PI ΔTS]

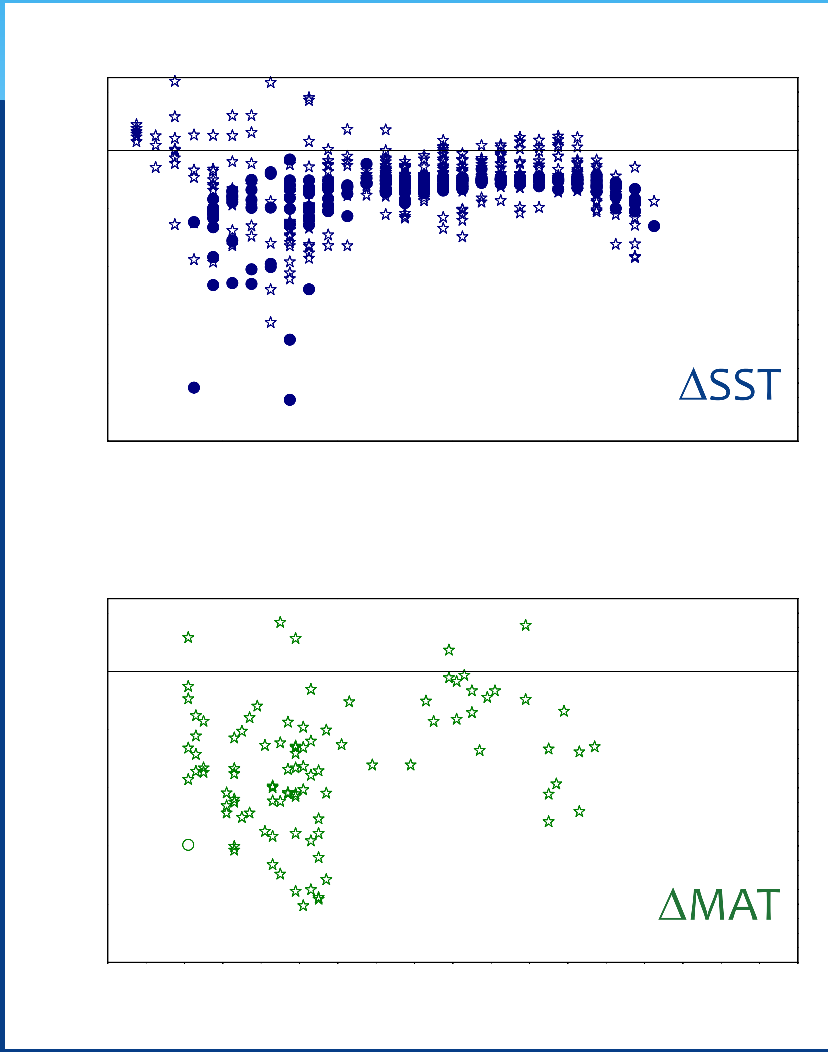
Terrestrial pollen-based (Bartlein et al. 2011)
Marine-based multi-proxy (MARGO 2009)

Modeled ΔTS over open ocean and land compares well in magnitude and pattern to latest Proxy Reconstructions



LGM vs. Proxy Data

Simulated LGM reproduces well the large scale spatial pattern in the proxy reconstructions.

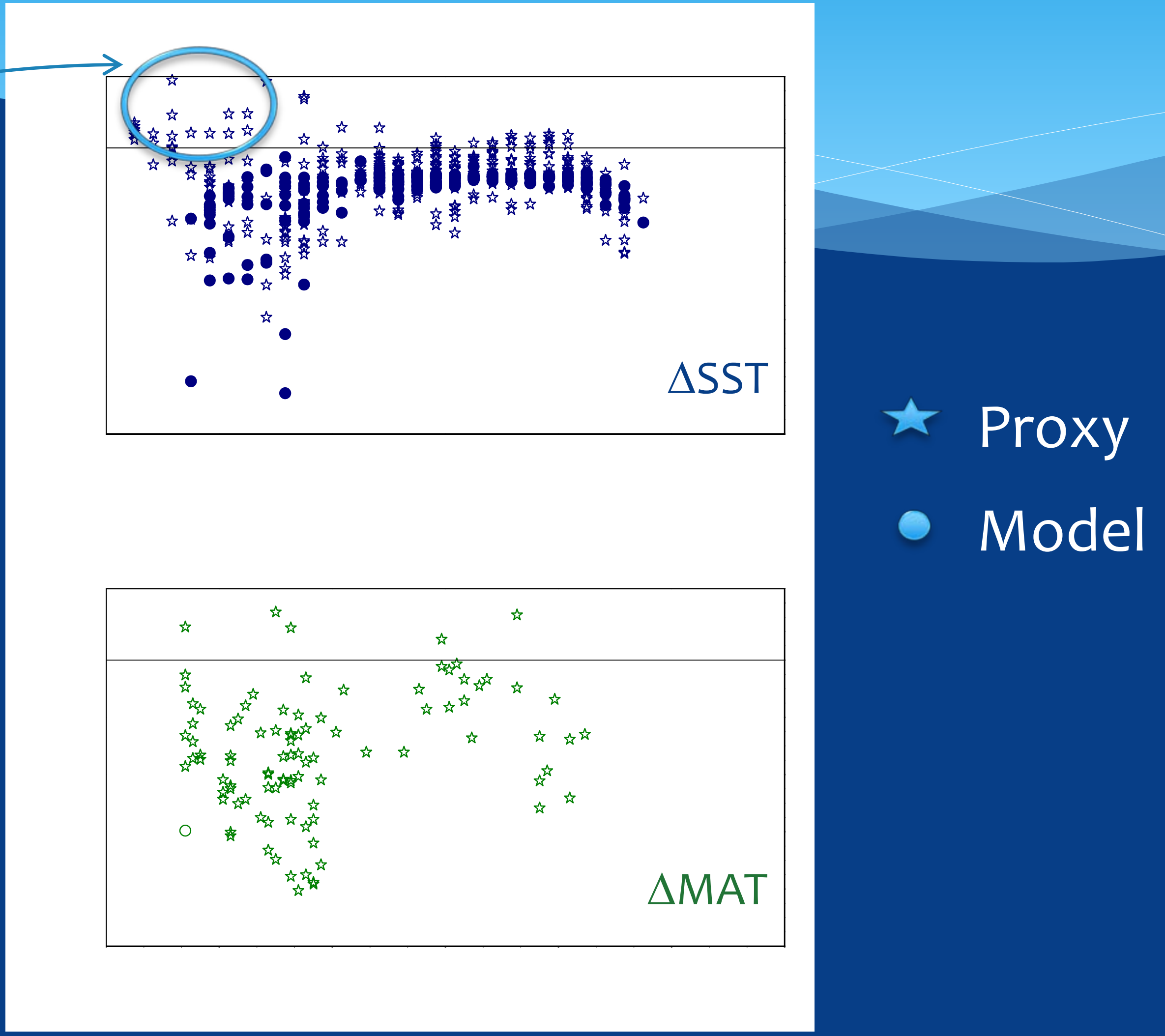


Proxy

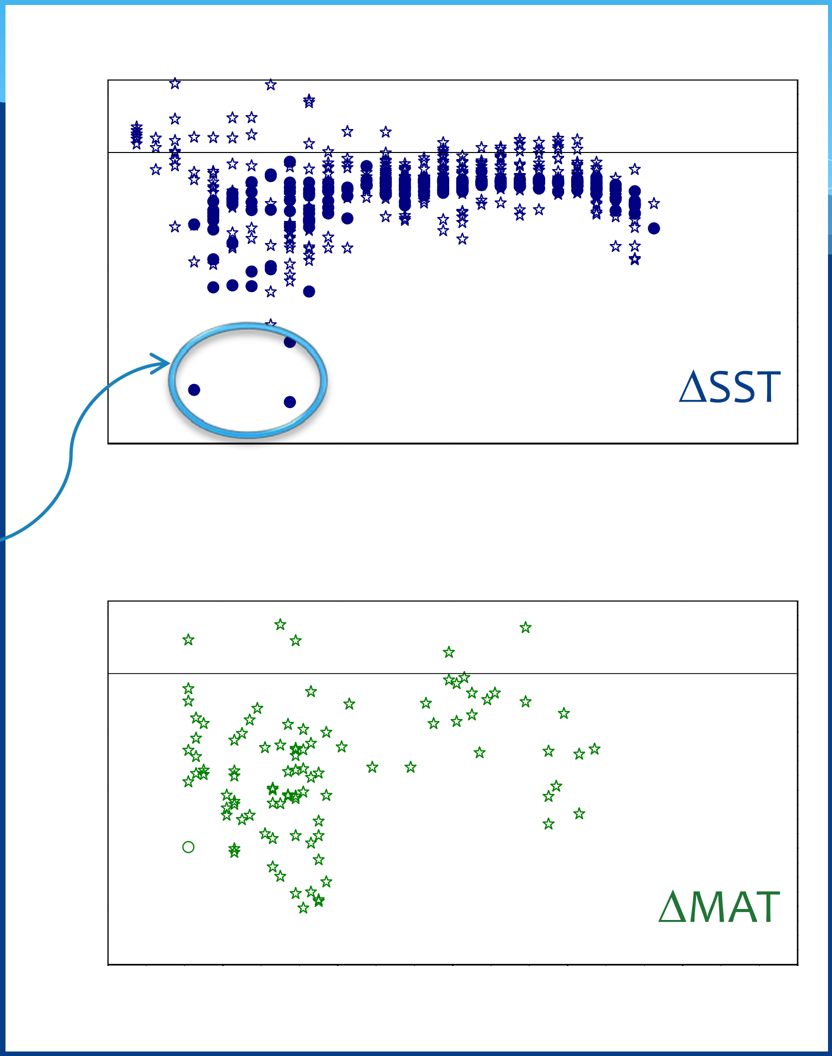
Model

LGM vs. Proxy Data

Proxy warming over North Atlantic Near(Under?) Seaice has high uncertainty.



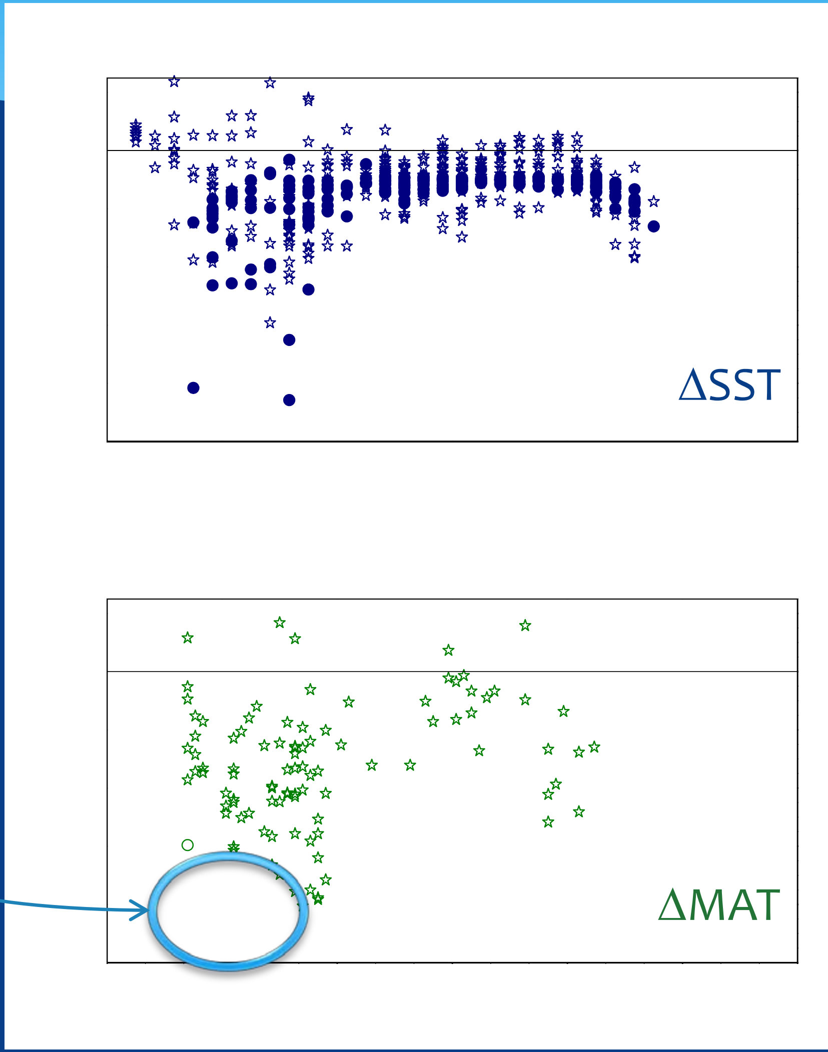
LGM vs. Proxy Data



Model is colder near Boundaries in North Atlantic

- Proxy
- Model

LGM vs. Proxy Data

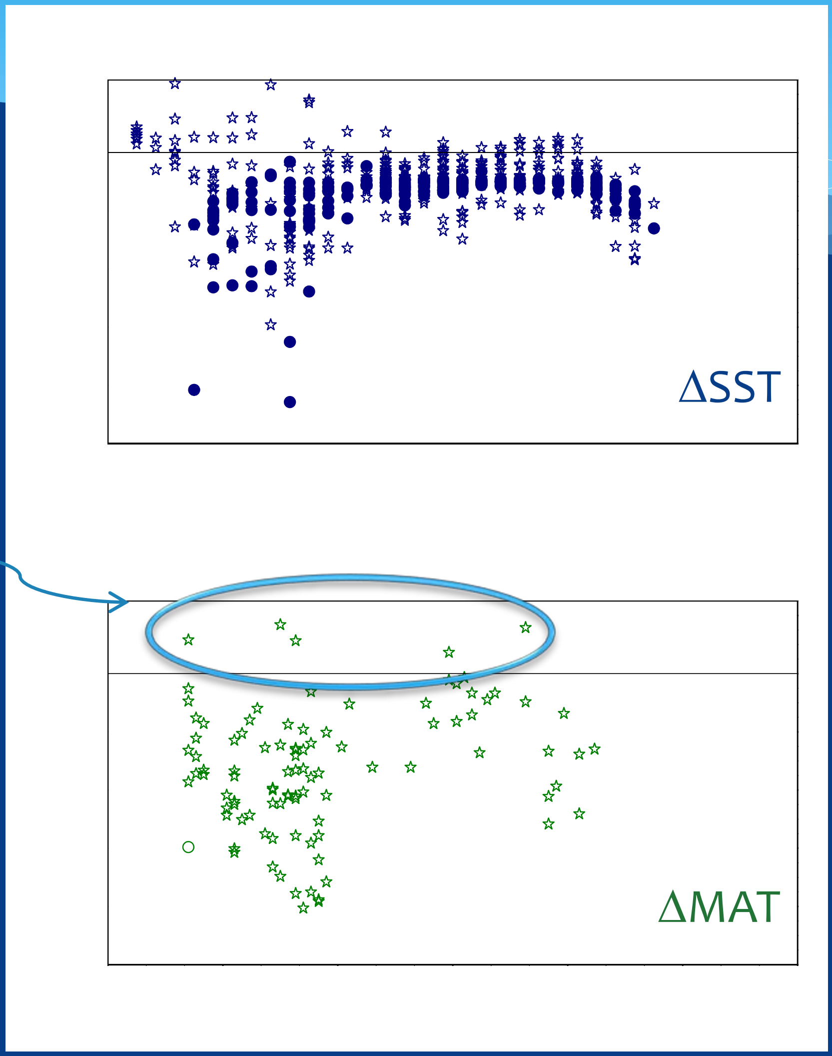


- Proxy
- Model

Model is colder over high latitude Eurasia.

LGM vs. Proxy Data

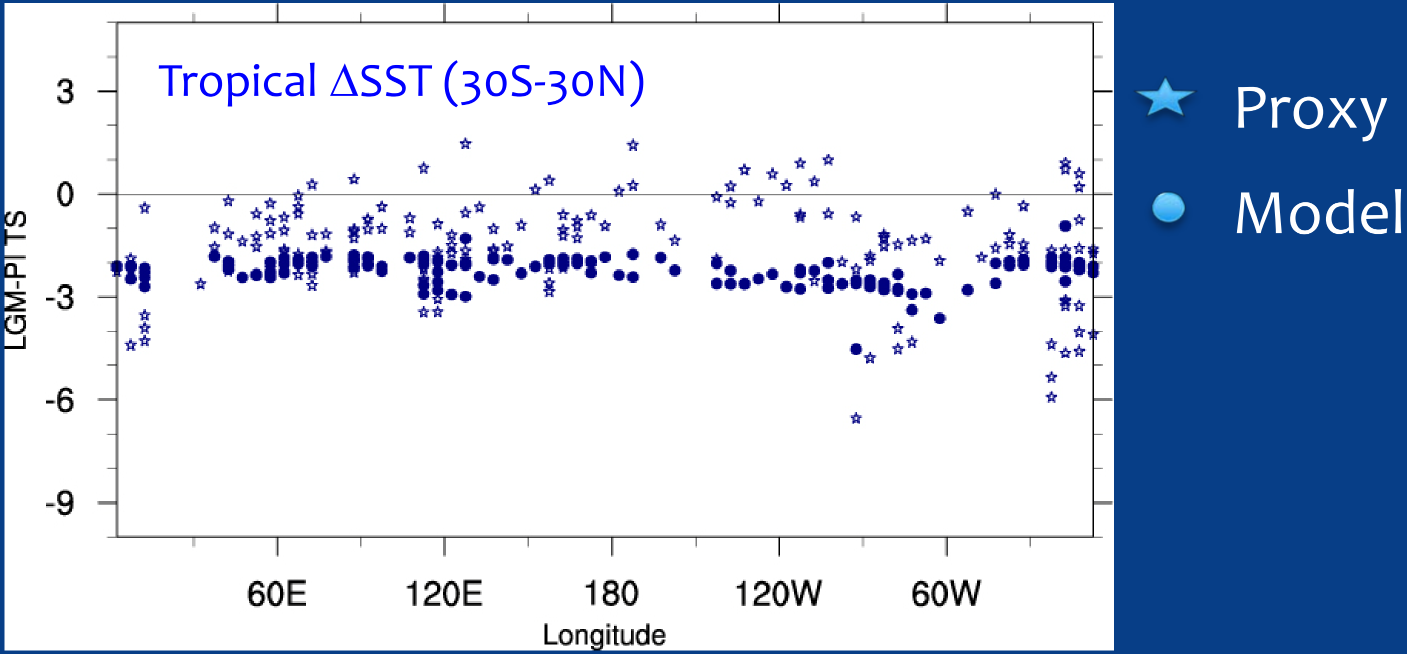
CCSM4 LGM doesn't show terrestrial warming as in proxies



- Proxy
- Model

LGM vs. Proxy Data

Model shows more uniform cooling across tropical oceans.



LGM compares reasonably well to available Proxy Reconstructions (within ~1.2°C).

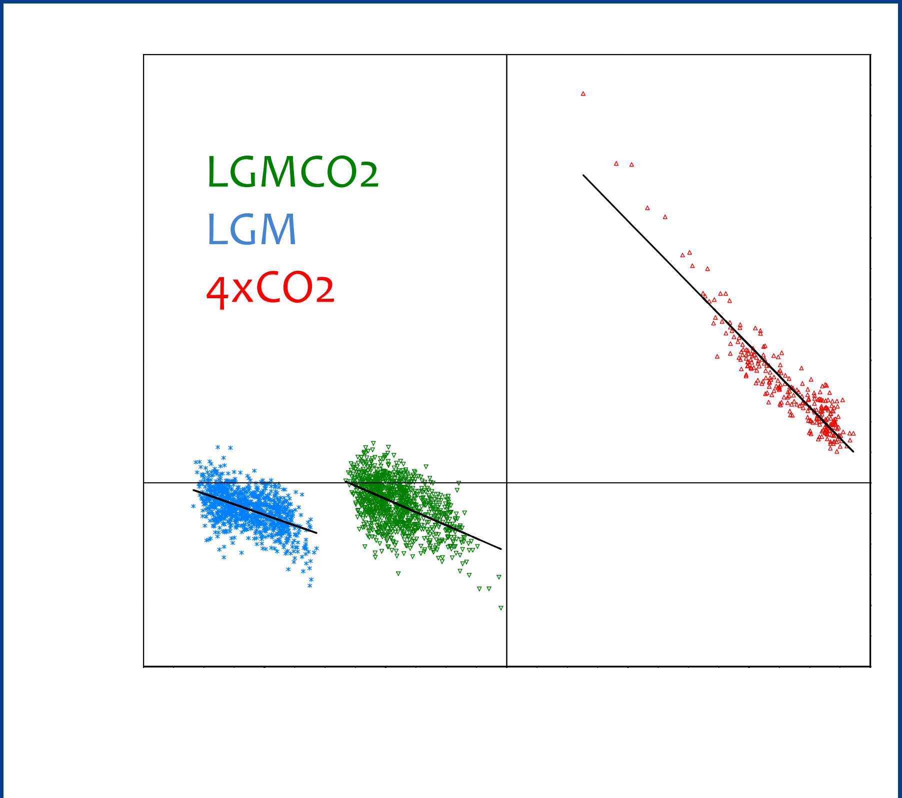
	PROXY	LGM
GLOBAL ΔSST	-2.0	-2.9
ΔMAT	-6.1	-7.3
TROPICS ΔSST (+/-30°)	-1.5(+/- 1.2)	-2.2
ΔMAT	-3.2	-3.5

but with a consistent cold bias.

Gregory et al. (2004) method to diagnose Climate Response Parameter λ

$$\Delta Q = \Delta F - \lambda \Delta TS$$

Net TOA Imbalance = Forcing – (Climate Response)



Case	ΔF W m^{-2}	ΔTSeq °C	λc W m^{-2}/°C	ECS °C
LGMCO2	-2.3	-2.6	0.9	4.2
LGM	-6.2 (+/- 0.6)	-5.5	1.1 (+/- 0.1)	3.3 (+/- 0.3)
4xCO2	7.4	6.2	1.2	3.1

At Equilibrium: $\lambda = \Delta F / \Delta TS$

LGM ΔF estimated by regression over first 20 years; Other cases by IPCC formula.

Use Gregory et al. (2004) method to diagnose Climate Response Parameter λ:

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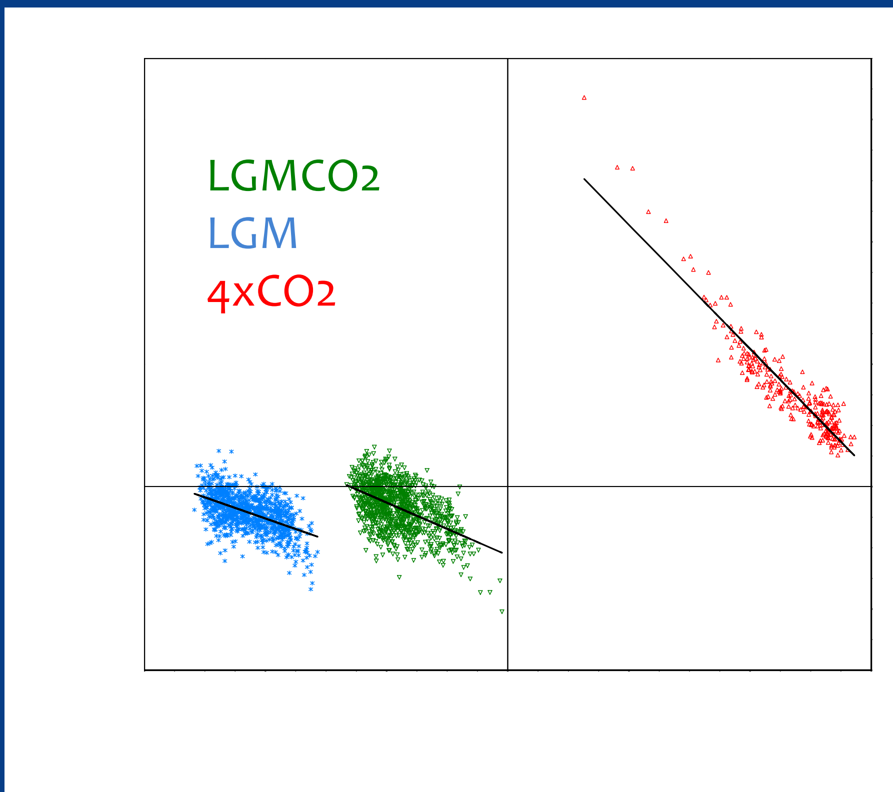

Case	ΔF $W\ m^{-2}$	$\Delta TSeq$ °C	λc $W\ m^{-2}/°C$	ECS °C
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$\Delta TSeq$ estimated as ΔTS-intercept ($\Delta Q=0$)

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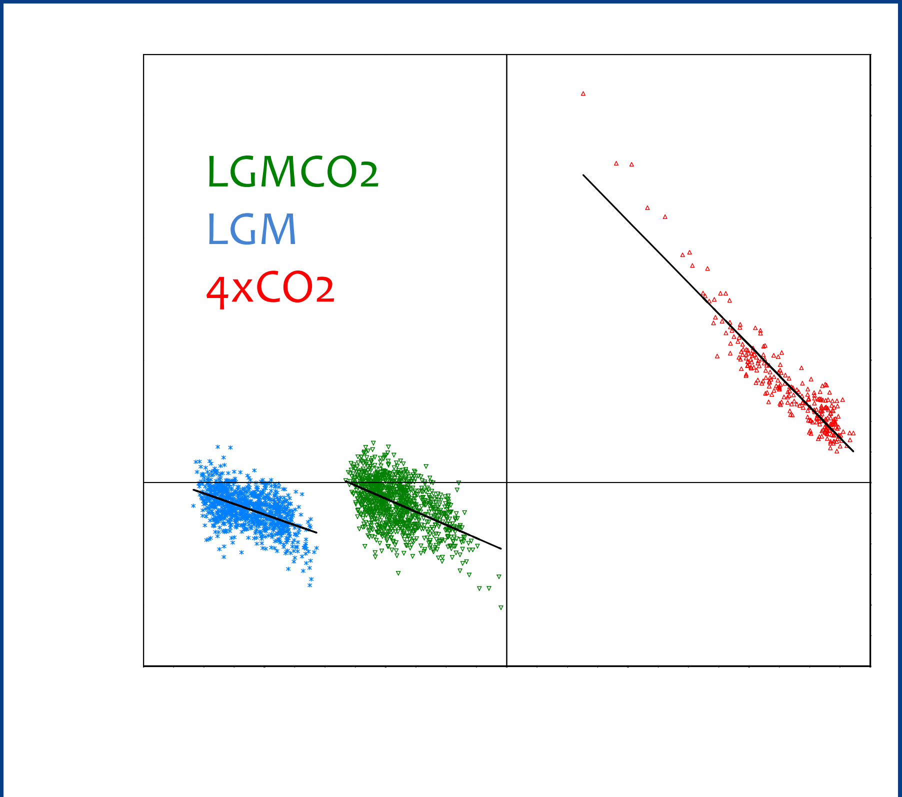

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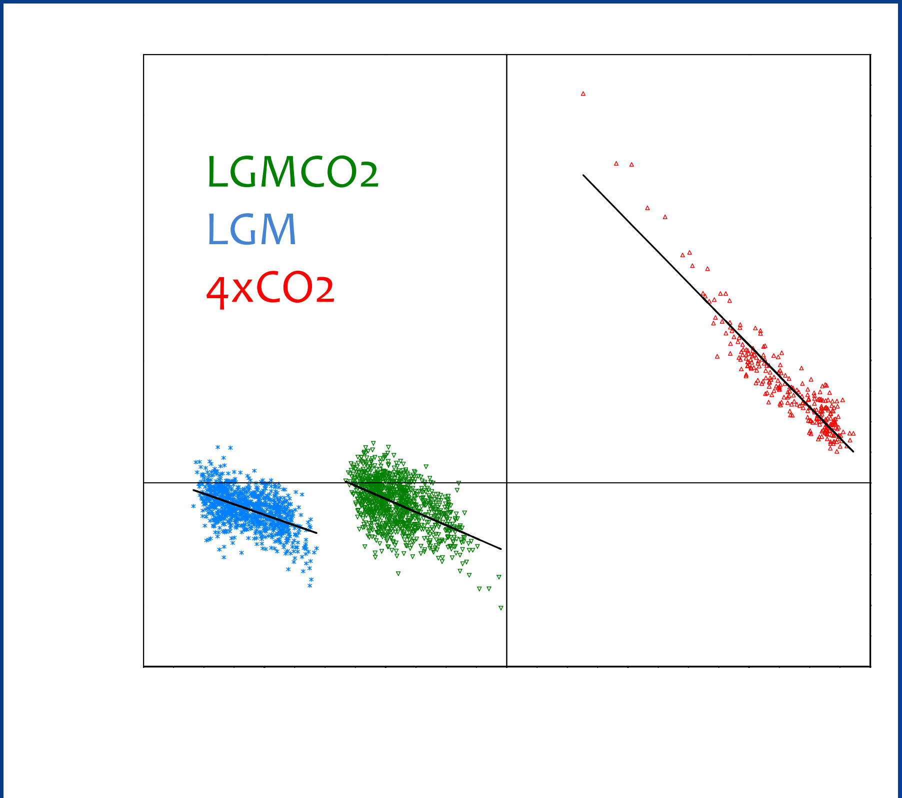
$$\lambda_c = \Delta F / \Delta TSeq$$

Use Gregory et al. (2004) method to diagnose Climate Response Parameter λ:

$$\Delta Q = \Delta F - \lambda \Delta TS$$

Net TOA Imbalance = Forcing – (Climate Response)



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$$ECS = 3.7 Wm^{-2}/\lambda_c$$

Equilibrium Climate Sensitivity

(ΔTS for 2xCO2 forcing)

Bitz et al. 2011 CCSM4; ECS = 3.2°C.

Use Gregory et al. (2004) method to diagnose Climate Response Parameter λ:

$$\Delta Q = \Delta F - \lambda \Delta TS$$

Net TOA Imbalance = Forcing – (Climate Response)

IPCC AR4: ECS = 2-4.5°C (to $2xCO_2$ forcing) with 3°C as best estimate.

Schmittner et al. (2011)
ECS = 1.7-2.6°C, with 2.3°C as best estimate. (Statistical approach using Proxy Reconstructions combined with EMIC simulations of LGM)

Bitz et al. (2011) CCSM4-SOM
ECS = 3.2°C

Case	ΔF W m^{-2}	$\Delta TSeq$ °C	λc W m^{-2}/°C	ECS °C
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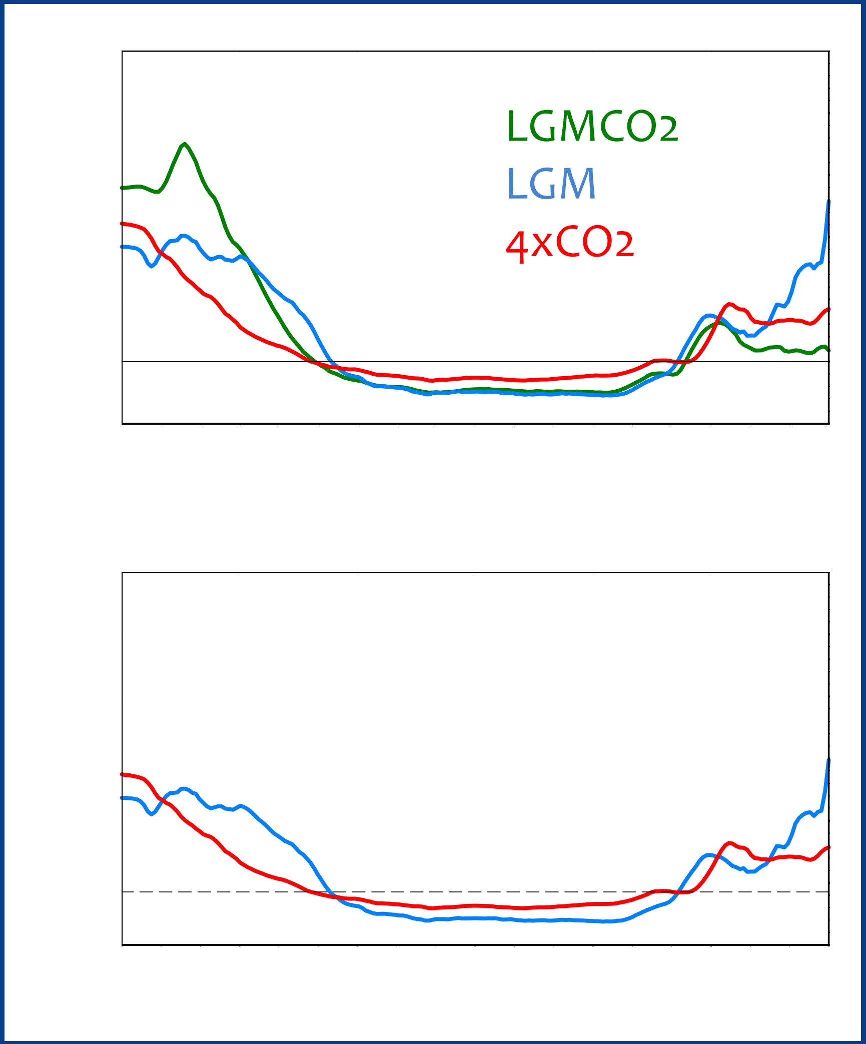
Equilibrium Climate Sensitivity
(ΔTS for $2xCO_2$ forcing)



Polar Amplification =

$\Delta TS(y)/\Delta TS_{glob}$

$\Delta TS(y)/(\Delta F - \Delta Q)$

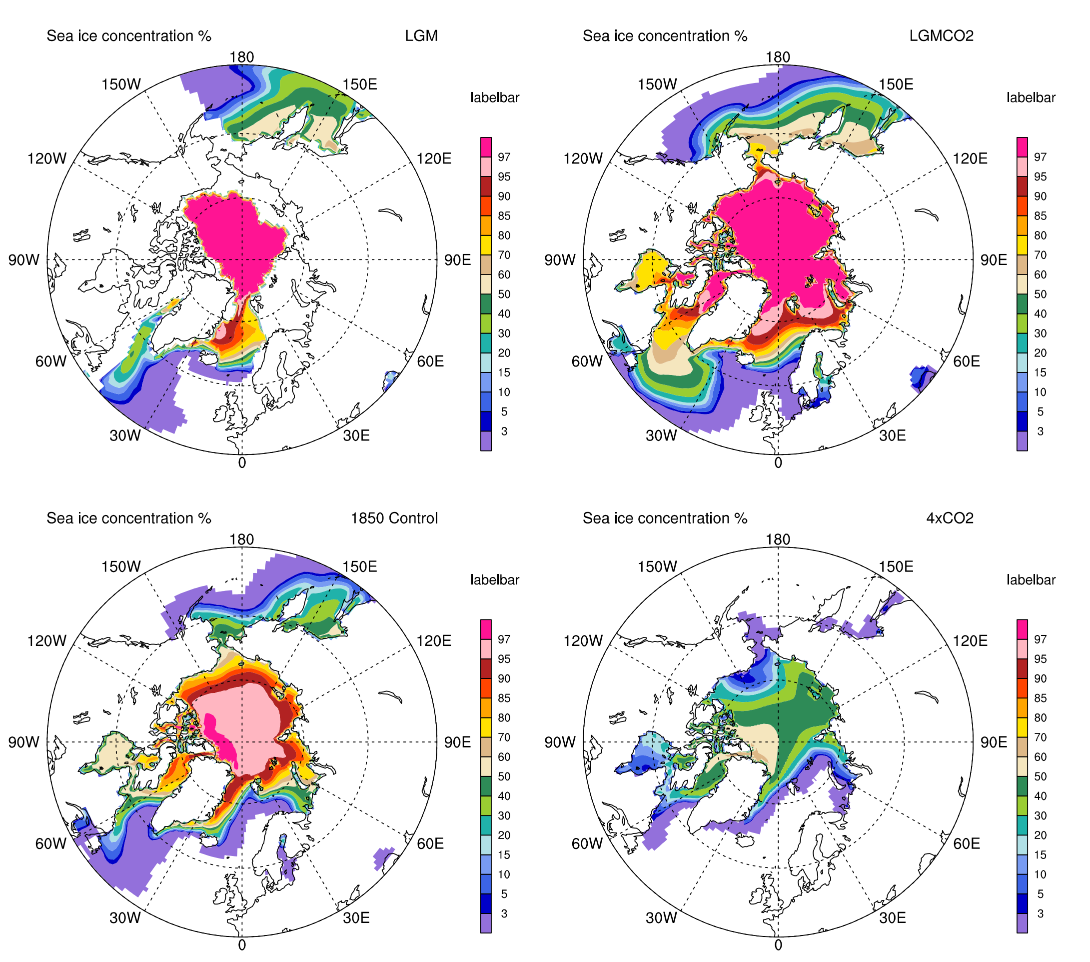
NH Sea Ice Concentration

LGM

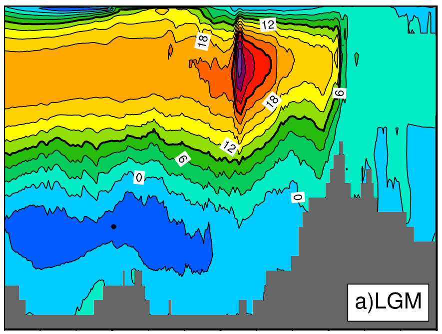
LGMCO2

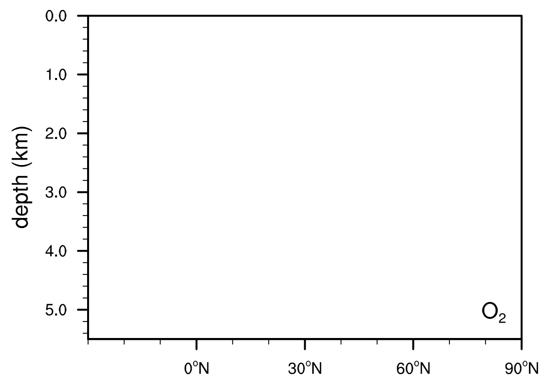
PI

4xCO2



Atlantic Meridional Overturning Circulation





Both LGMCO2 and 4xCO2 show a weakening in AMOC (and northward ocean heat transport).

LGM simulation shows a strengthening of AMOC (and northward ocean heat transport) in response to stronger wind stresses.

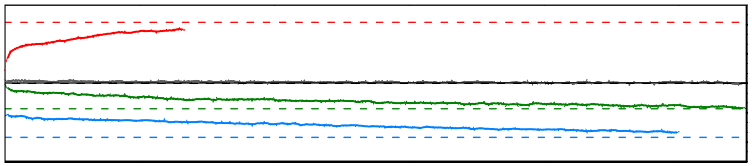
Conclusions

1. The LGM simulation compares well to available proxy temperature reconstructions, however, there is a consistent cold bias with no simulated warming as in the proxy reconstructions.

2. CCSM4 LGM simulation predicts an ECS = ~3.3°C comparable to Bitz et al. 2011 CCSM4-SOM ECS.

3. CCSM4 shows a greater climate sensitivity (and a greater polar amplification in NH) to a lowering to glacial CO2 levels than either a 4-fold increase or the full glacial forcing including the ice sheets.

4. Weakening AMOC response in LGMCO2 may act as a positive feedback to increased sea ice growth in North Atlantic, enhancing the positive ice/snow albedo feedback.



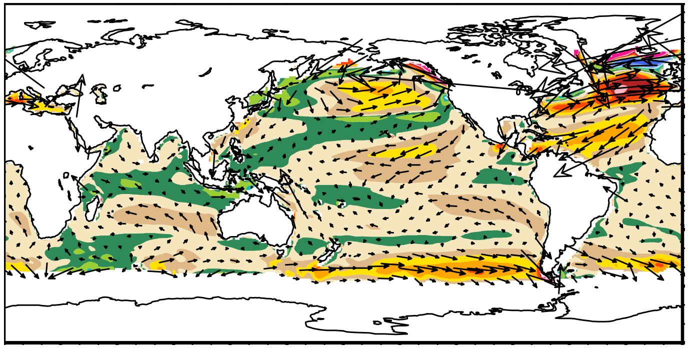
tivity

LGMCO2
LGM
4xCO2

$$\lambda_{eff} = (\Delta Q - \Delta F)/\Delta TS$$

$$ECS = 3.7 Wm^{-2}/\lambda_{eff}$$

Wind Stress Anomalies



0.12
0.09
0.06
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.06
09